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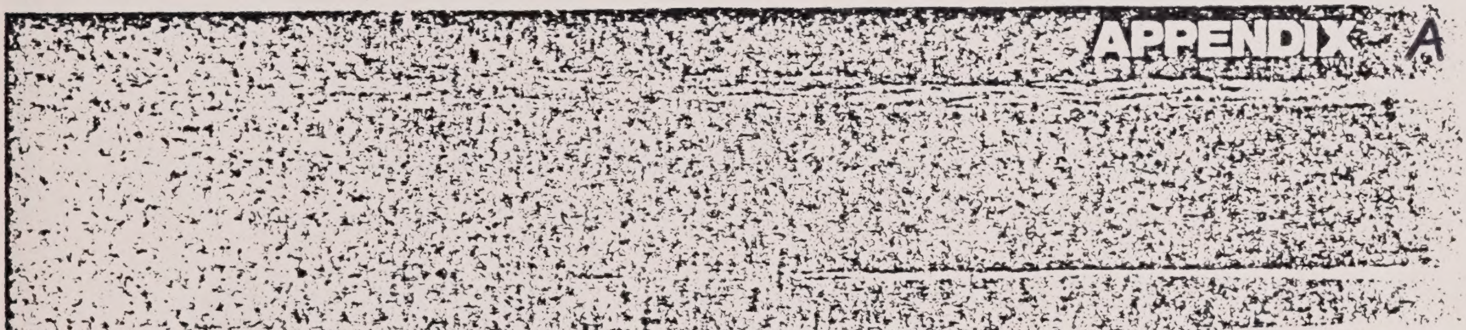
APPENDIX A



HILLSIDE GENERAL PLAN/ ENVIRONMENTAL IMPACT REPORT

City of Cupertino Slope-Density Formula Rounding Off Policy

The City Council, during its meeting of March 7, 1977, adopted the following policy regarding the rounding up of a numerical dwelling unit yield resulting from application of a slope-density formula:

> "The rounding up of the numerical yield resulting from application of a slope-density formula may be permitted in cases where the incremental increase in density from the actual yield to the rounded yield will not result in a 10% increase of the actual yield. In no case shall an actual yield be rounded up to the next whole number unless the fractional number is .5 or greater."

TABLE OF CONTENTS

Section 1: Purpose of This Document

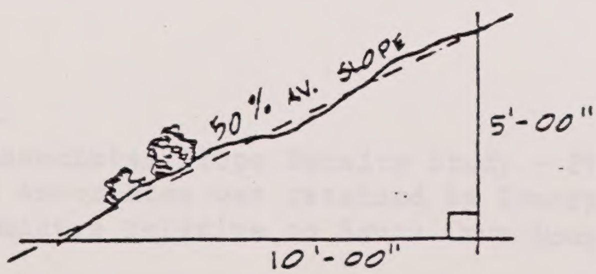
This document has been prepared with the intent of acquainting the general reader with the slope-density approach to determining the intensity of residential development. The slope-density approach was incorporated in the hillside plan in order to develop an equitable means of assigning dwelling unit credit to property owners. In addition to offering the advantage of equal treatment for property owners, the slope-density formula can also be designed to reflect judgments regarding aesthetics and other factors into a mathematical model which determines the number of units per acre on a given piece of property based upon the average steepness of the land. Generally speaking, the steeper the average slope of the property, the fewer the number of units which will be permitted.

Although the slope-density formula can be used as an effective means to control development intensity, the formula itself cannot determine the ideal development pattern. The formula determines only the total number of dwelling units, allowable on the property, based upon the average slope; it does not determine the optimum location of those units on the property. Exogenous factors not regulated by the slope-density formula such as grading, tree removal, or other environmental factors would be regulated by other means. The slope-density formulas do not represent by themselves a complete safeguard against development detrimental to the environment; but, together with other conservation measures, they are considered a valuable planning device.

Section 2: Discussion of "Slope"

Steepness of terrain can be defined in several ways: As the relationship between the sides of the triangle representing a vertical section of a hill, or as the angle between the terrain and the horizontal plain, to name two. Unfortunately, the definitions of the terms "slope", "grade", "gradient", "batter", and of the expression "the slpe is 1 to ..." are not well known or uniformly applied causing much confusion. For purposes of this section, the concept of steepness of terrain will be defined and discussed as a "percentage of slope".

"Percent of slope" is defined as a measurement of steepness of slope which is the ratio between vertical and horizontal distances expressed in percent. As illustrated below, a 50% slope is one which rises vertically 5 ft. in a 10 ft. horizontal distance.



Section I. Purpose of This Document

This document has been prepared with the intent of supplementing the general [illegible] the slope-density approach to determining the intensity of residential development. The slope-density approach was incorporated in the Hillside Plan in order to develop an equitable means of assigning dwelling units to hill property owners. In addition to reflecting the advantage of equal treatment for property owners, the slope-density formula was also developed to reflect [illegible] capability [illegible] and local district land, a mathematical model which determines the number of units per acre on a given piece of property based upon the average steepness of the land. Generally speaking, the steeper the average slope of the property, the fewer the number of units which will be permissible.

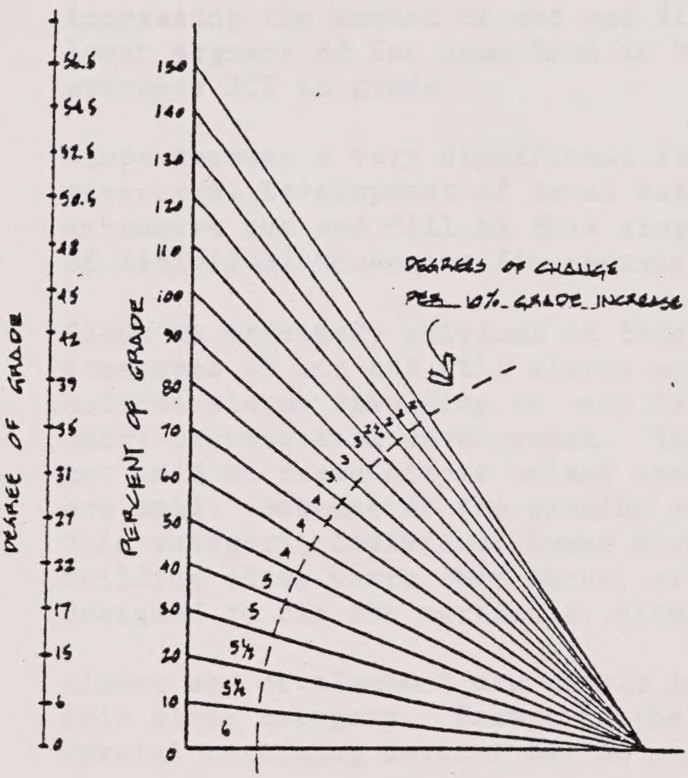
Although the slope-density formula can be used as an effective means to control development intensity, the formula itself cannot determine the final development pattern. The formula determines only the total number of dwelling units, allowable on the property, based upon its average natural slope and [illegible] the maximum number of units which [illegible] on the property. [illegible] factors are neglected by the slope-density formula such as geology, tree removal, or other environmental factors, which are regulated by other means. The slope-density formula [illegible] a [illegible] against development [illegible] to the environment, but [illegible] together with other [illegible] measures, they are considered a valuable planning device.

Section II. Measurement of Slope

The steepness of terrain can be defined in several ways: as the relationship between the slope of the triangle representing a vertical section of a hill, or as the angle between the surface and the horizontal plane, or some such. Unfortunately, the definitions of the words "slope", "grade", "gradient", "percent", and of the expression "one slope is 1 on 2" are not well known or uniformly accepted among [illegible] engineers. For purposes of this section, the concept of steepness of terrain will be defined and discussed as a "percentage of slope".

"Percent of slope" is defined as a measurement of steepness of slope which is the ratio between vertical and horizontal distances expressed in percent. As illustrated below, a 20% slope is one which rises vertically 2 ft. in a 10 ft. horizontal distance.

One of the most common confusions of terminology relative to terrain steepness is the synonymous usage of "percent of grade" and "degree of grade". However, as the illustration below indicates, as percent of grade increase, land becomes steeper at a decreasing rate. The present slope-density formulas specified by the City of Cupertino require more land for development as the rate of percent of grade increases. Thus, the relationship between percent of grade and degree of grade is inverse rather than corresponding.



To more accurately assess the impact of steepness of terrain on the feasibility of residential development, it might be helpful to examine some of phenomenon commonly associated with increasing percentages of slope steepness.[1]

1. William Spangle & Associates Slope Density Study - Phase I. (Published October, 1967 William Spangle and Associates was retained by County to assist the effort of Planning Policy Committee relative to Santa Cruz Mountain Study and Montebello Ridge Study.

e of the most common definitions of terminology relative to terrain steepness is the synonymous usage of 'percent of grade' and 'degree of grade'. However, as the illustration below indicates, as percent of grade increases, land becomes steeper at a decreasing rate. The greatest slope density formulas introduced by the City of Cupertino require more land for development as the rate of percent of grade increases. Thus, the relationship between percent of grade and degree of grade is inverse rather than corresponding.

more accurately assess the impact of steepness of terrain on the feasibility of residential development, it might be helpful to examine some of the engineering commonly associated with increasing percentages of slope.

William Spangle & Associates Slope Density Study - Thomas L. O'Halloran, William Spangle and Associates was retained by County to assist the ... Planning Policy Committee to ... Study.

Percent of Slope	Description of Slope Problems
0-5%	Relative level land. Little or no development problems due to steepness of slope.
5-15%	Minimum slope problems increasing to significant slope problems at 15%. 15% is the maximum grade often considered desirable on subdivision streets. Above 15%, roads must run diagonally to, rather than at right angles to contours increasing the amount of cut and fill. For example, the lower segment of San Juan Road in the Cupertino foothills averages 20% in grade.
15-30%	Slope becomes a very significant factor in development at this steepness. Development of level building sites requires extensive cut and fill in this slope category and the design of individual houses to fit terrain becomes important.
30-50%	Slope is extremely critical in this range. Allowable steepness of cut and fill slopes approach or coincide with natural slopes resulting in very large cuts and fills under conventional development. In some cases, fill will not hold on these slopes unless special retaining devices are used. Because of the grading problems associated with this category, individual homes should be placed on natural building sites where they occur, or buildings should be designed to fit the particular site.
50%+	Almost any development can result in extreme disturbances in this slope category. Except in the most stable native material, special retaining devices may be needed.

Section Three: Description of Slope-Density Formulas

I) The "Foothill Modified" Formula

$$d = 1.85 + 1.65 \cos \left\{(s-5) \times 4.5\right\}$$

$$5 \leq s \leq 44$$

The "Foothill Modified" formula is designed for application to those properties in the "Fringe" of the Hillside study area with average slopes less than 10%. The formula assumes availability of municipal services. Beginning at credit of 3.5 dwelling units/gr. acre, the formula follows a cosine curve of decreasing density credit with increase of slope, achieving a constant above 43% average slope.

II) The "Foothill Modified 1/2 Acre" Formula

$$d = 1.85 + 1.65 \cos \left\{(s-5) \times 4.5\right\}$$

$$22 \leq s \leq 44$$

This formula is applied in the Urban Service Area to those properties where a full range of municipal utility services are available. The formula begins at density of 1/2 acre per dwelling unit which holds constant at 22% average slope. From 22% to 43% average slope, the formula follows a cosine curve of decreasing density credit with increasing slope. The density credit above 43% average slope remains constant at 0.20 dwelling units/gr. acre.

III. The "Semi-Rural 5 Acre" Formula

$$d = 0.43 + 0.23 \cos (s \times 3.4)$$

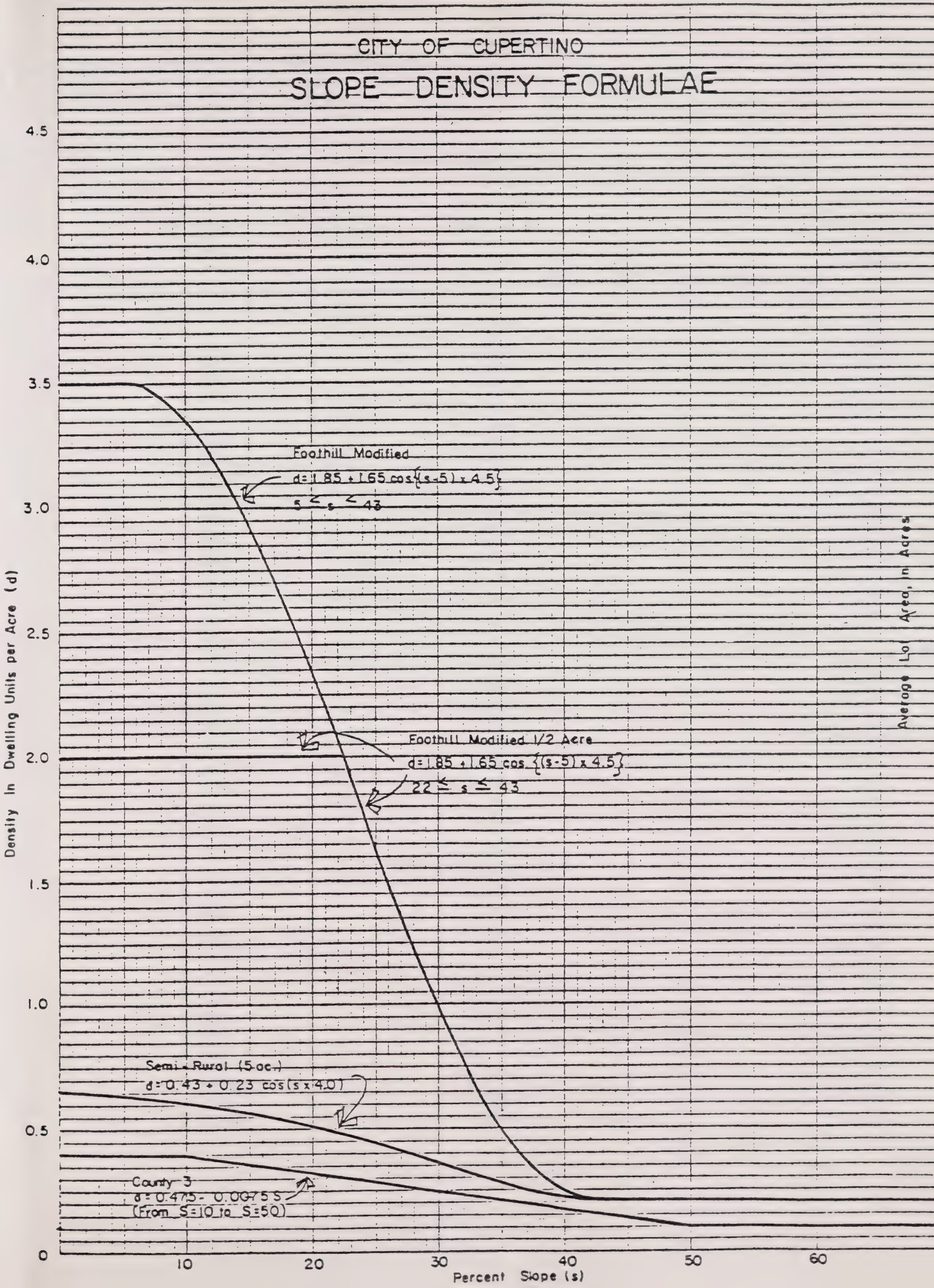
The Semi-Rural Formula is intended for analysis of properties within the upper reaches of Regnart Canyon where a full range of urban services is not available. The formula begins at a density 0.66 dwelling units per acre and follows a regular cosine curve 42% average slope. Above 42% average slope, the formula holds a constant density credit of 0.20 dwelling units per gross acre.

IV. The "County III" Formula

$$d = 0.475 - 0.0075(s)$$

$$10 \leq s \leq 50$$

This formula is applied to those properties described on Exhibit C-1 which lie outside of the Urban Service Area where no municipal utility services are provided. The formula is of the "polygonal" type, with a constant of 0.40 dwelling unit per gross acre from 0-10% average slope, a declining dwelling unit credit from 10%-50% average slope and a constant dwelling unit credit of 0.10 dwelling units per acre for properties above 50% average slope.


CITY OF CUPERTINO
SLOPE DENSITY FORMULAE
Foothill Modified
d=1.85 + 1.65 cos{(s-5) x 4.5}
5 ≤ s ≤ 43
Foothill Modified 1/2 Acre
d=1.85 + 1.65 cos {(s-5) x 4.5}
22 ≤ s ≤ 43
Semi - Rural (5 ac.)
d=0.43 + 0.23 cos(s x 4.0)
County 3
d=0.475 - 0.0075 S
(From S=10 to S=50)
Density In Dwelling Units per Acre (d)
Percent Slope (s)
Average Lot Area, in Acres
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
10
20
30
40
50
60

Slope-Density Formula: "Foothill Modified"

$d = 1.85 + 1.65 \cos \left\{ (s-5) \times 4.8 \right\}$

$5 \leq s \leq 44$

Slope s	Density D.U.per gr.acre d	Gr.acres per D.U. 1/d	Average lot area gr.sq.ft. 43,560/d
0-5	3.500	0.285	12,445
6	3.494	0.286	12,467
7	3.477	0.288	12,528
8	3.448	0.290	12,633
9	3.408	0.293	12,781
10	3.357	0.298	12,975
11	3.296	0.303	13,868
12	3.224	0.310	13,511
13	3.143	0.318	13,868
14	3.053	0.328	14,267
15	2.954	0.339	14,746
16	2.848	0.351	15,294
17	2.734	0.366	15,932
18	2.614	0.383	16,664
19	2.489	0.402	17,501
20	2.360	0.424	18,457
21	2.227	0.449	19,559
22	2.000	0.500	21,780
23	1.954	0.512	22,292
24	1.815	0.551	24,000
25	1.678	0.596	25,959
26	1.541	0.649	28,267
27	1.406	0.711	30,981
28	1.275	0.784	34,164
29	1.147	0.872	37,977
30	1.025	0.976	42,497
31	0.908	1.101	47,973
32	0.798	1.253	55,209
33	0.696	1.437	62,586
34	0.601	1.664	72,479
35	0.515	1.942	84,582
36	0.439	2.278	99,225
37	0.372	2.688	117,096
38	0.315	3.175	138,285
39	0.270	3.698	161,081
40	0.236	4.240	184,576
41	0.213	4.694	204,507
42	0.201	4.980	216,716
43	0.200	5.000	217,800

Slope-Density Formula: "Foothill Modified ½ Acre"

$$d = 1.85 + 1.65 \cos \left\{(s-5) \times 4.8\right\}$$

$$5 \leq s \leq 44$$

Slope s	Density D.U.per gr.acre d	Gr.acres per D.U. 1/d	Average lot area gr.sq.ft. 43,560/d
0-22	2.000	0.500	21,780
23	1.954	0.512	22,292
24	1.815	0.551	24,000
25	1.678	0.596	25,959
26	1.541	0.649	28,267
27	1.406	0.711	30,981
28	1.275	0.784	34,164
29	1.147	0.872	37,977
30	1.025	0.976	42,497
31	0.908	1.101	47,973
32	0.798	1.253	55,209
33	0.696	1.437	62,586
34	0.601	1.664	72,479
35	0.515	1.942	84,582
36	0.439	2.278	99,225
37	0.372	2.688	117,096
38	0.315	3.175	138,285
39	0.270	3.698	161,081
40	0.236	4.240	184,576
41	0.213	4.694	204,507
42	0.201	4,980	216,716
43	0.200	5,000	217,800

Slope Density Formula: "Semi-Rural - 5 Ac"

$0.43 + 0.23 \cos (s \times 4.0)$

$0 \leq s \leq 45$

Slope % s	Density D.U.per gr.acre d	Gr.acres per D.U. 1/d	Average lot area gr.sq.ft. 43,560/d	Slope % s	Density D.U.per gr.acre d	Gr.acres per D.U. 1/d	Average lot area gr.sq.ft. 43,560/d
5	.660	1.515	66000	30	.315	3.175	138285
6	.640	1.562	68050	31	.301	3.318	144532
7	.633	1.579	68806	32	.288	3.467	151041
8	.625	1.599	69690	33	.276	3.622	157768
9	.616	1.623	70705	34	.265	3.779	164653
10	.606	1.649	71858	35	2.54	3.939	171624
11	.595	1.679	73154	36	.244	4.099	178582
12	.584	1.712	74601	37	.234	4.256	185401
13	.572	1.749	76206	38	.227	4.407	191960
14	.559	1.789	77924	39	.219	4.548	198103
15	.545	1.835	79926	40	.214	4.675	203679
16	.531	1.884	82060	41	.208	4.787	209423
17	.516	1.937	84392	42	.205	4.877	212460
18	.501	1.996	86933	43	.202	4.944	215389
19	.486	2.059	89695	44	.201	4.986	217196
20	.469	2.128	92692	45	.200	5.000	217800
21	.454	2.202	95938	46 >			
22	.438	2.282	99445				
23	.422	2.369	103229				
24	.406	2.463	107301				
25	.390	2.564	111674				
26	.374	2.671	116359				
27	.359	2.786	121362				
28	.343	2.908	126686				
29	.329	3.038	132330				

Slope Density Formula: Santa Clara County #3

$d = 0.475 - 0.0075s$

$0 \leq s \leq 50$

Slope % s	Density D.U.per gross acre d	Average lot area sq.ft. 43,560/d	Slope % s	Density D.U.per gross acre d	Average lot area sq.ft. 43,560/d
0	0.4000	108,900	25	0.2875	151,500
1	0.4000	108,900	26	0.2800	155,600
2	0.4000	108,900	27	0.2725	159,900
3	0.4000	108,900	28	0.2650	164,400
4	0.4000	108,900	29	0.2575	169,200
5	0.4000	108,900	30	0.2500	174,200
6	0.4000	108,900	31	0.2425	179,600
7	0.4000	108,900	32	0.2350	185,400
8	0.4000	108,900	33	0.2275	191,500
9	0.4000	108,900	34	0.2200	198,000
10	0.4000	108,900	35	0.2125	205,000
11	0.3925	111,000	36	0.2050	212,500
12	0.3850	113,100	37	0.1975	220,600
13	0.3775	115,400	38	0.1900	229,300
14	0.3700	117,700	39	0.1825	238,700
15	0.3625	120,200	40	0.1750	248,900
16	0.3550	122,700	41	0.1675	260,100
17	0.3475	125,400	42	0.1600	272,300
18	0.3400	128,100	43	0.1525	285,600
19	0.3325	131,000	44	0.1450	300,400
20	0.3250	134,000	45	0.1375	316,800
21	0.3175	137,200	46	0.1300	335,100
22	0.3100	140,500	47	0.1225	355,600
23	0.3025	144,000	48	0.1150	378,800
24	0.2950	147,700	49	0.1075	405,200
			50	0.1000	435,600
			over 50	0.1000	435,600

Section 4: How to Conduct a Slope-Density Analysis (Map Wheel Method)

The computation of density using a slope-density formula is relatively simple once the basic concepts are understood. This section of Appendix A describes the basic concepts in order to enable individuals to determine density. The City Planning staff will provide technical assistance; however, it is the responsibility of the owner or potential developer to provide accurate map materials used in the slope-density investigation for a specific property.

The City has map material which is accurate enough to provide an approximate slope-density evaluation. Accurate information needed to evaluate a specific development proposal must be provided by the owner or developer.

Step One: Selection of Map Material

To begin any slope-density investigation, it is important to select the proper mapping material. Maps on which measurements are made must be no smaller in scale than 1" = 200'. (1 ÷ 2400) All maps must be of the topographical type with contour intervals not less than 10 ft.

If the map wheel method is used for measuring contours, or if a polar planimeter is used for measurement of an area, maps on which such measurements are made must not be smaller in scale than 1" = 50' (1 ÷ 600); these maps may be enlarged from maps in a scale not less than 1" = 200'. Enlargement of maps in smaller scale than 1" = 200', or interpolation of contours is not permitted.

Step Two: Layout of Standard Grid System

The property for which area and slope are to be measured is divided into a network of "cells" constructed from a grid system spaced at 200 ft. intervals. In order to ensure a common reference point and to prevent the practice of "gerrymandering" the grid system to distort the average slope of the property, the grid system must be oriented parallel to the grid system utilized by Santa Clara County's 1" = 500' scale map series.

Figure 1 illustrates a hypothetical property divided into cells by a 200 ft. grid network. It is perhaps easiest to construct the 200' x 200' cells by beginning at an intersection point of perpendicular County grid lines ("Q" in Figure 1) and then measuring 200 ft. intervals along the two County grid lines until the entire property is covered with a network. After the grid lines have been laid out, it is helpful to number each 200 ft. square cell or part thereof. Whenever the grid lines divide the property into parts less than approximately 20,000 sq. ft., such areas shall be combined with each other or with other areas so that a number of parts

are formed with the areas approximately between 20,000 and 60,000 sq. ft. Cells formed by combining several subareas should be given a single number and should be shown on the map with "hooks" to indicate grouping (see area 2 on Figure 1). At this point, the investigator should obtain a copy of the "Slope-Density Grid Method Worksheet", Figure 2 of this document. Under Column A (land unit), each line should be numbered down the page to correspond with the total number of cells on the property. (Figure 2)

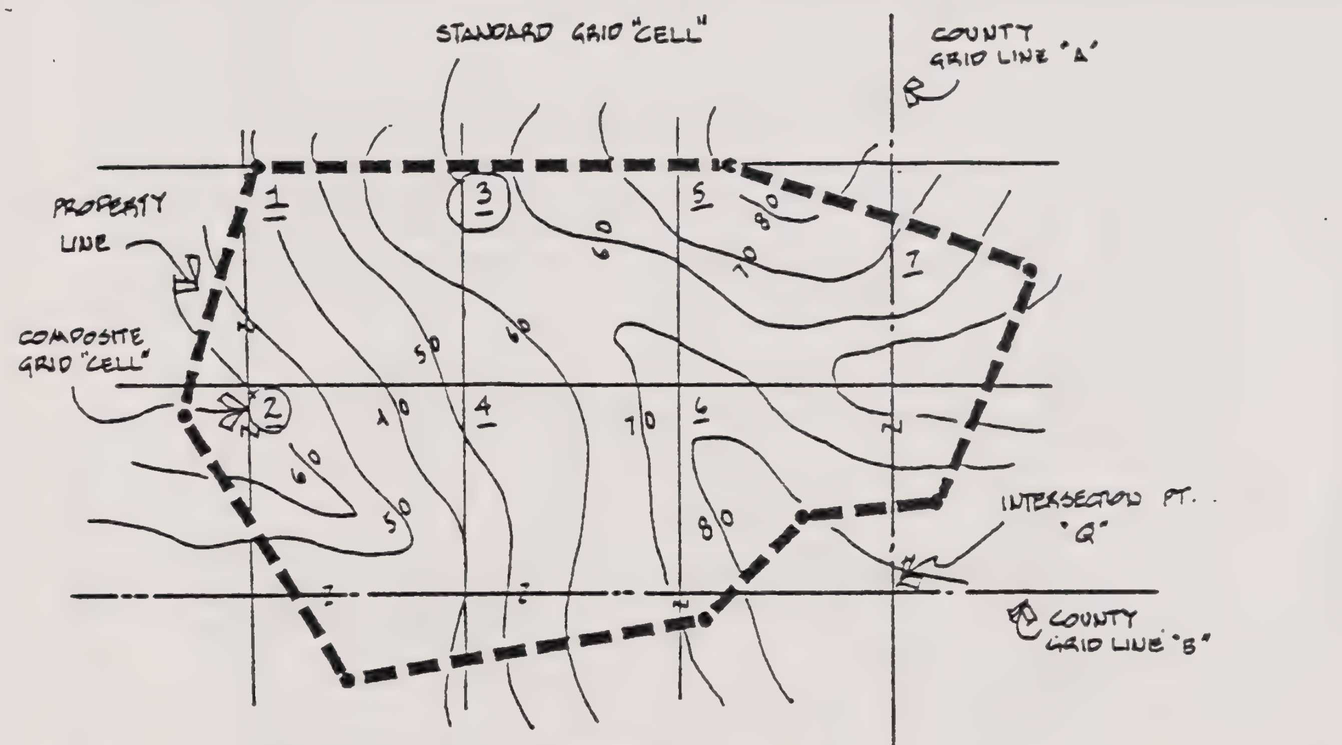


FIGURE 1

Step Three: Measurement of Area and Contour Length

With the map material properly prepared in Steps One and Two, we can now begin the actual mechanics of the slope-density analysis. The first task is to ascertain the acreage of the subject property. This acreage figure is obtained by measuring the area of each numbered cell divided by the 200 ft. grid, and then summing the results of the individual measurements. Since the standard grid cell measures 200' x 200', it is only necessary to measure the area of any non-standard size cell. Referring once again to the worksheet, as each cell is calculated for area, the results should be entered in Column B (and Column C optional). see Figure 2.

SLOPE DENSITY "GRID-METHOD" WORK SHEET

PROPERTY DESCRIPTION: EXAMPLE

						DWELLING UNIT CREDIT FROM SLOPE/DENSITY TABLES				
A	B	C	D	E	F	G	H	I	J	K
LAND UNIT	(acres) AREA	AREA (sq. ft.)	CONTOUR	Av. SLOPE	FACTOR	FOOTHILL MOD.	FOOTHILL MOD 1/2 AC.	SEMI-RURAL	COUNTY III	
1 COMPOS.	1.14	49600	750	15.3	0.545			0.621		
2 COMPOS.	1.18	51300	680	13.3	0.572			0.615		
3 STP.	0.92	40000	320	8.0	0.625			0.515		
4 COMPOS.	1.17	51000	490	9.6	0.606			0.709		
5	0.86	37600	470	12.6	0.572			0.492		
6 COMPOS.	0.92	40100	190	4.8	0.660			0.607		
7	0.56	24300	210	8.6	0.616			0.345		
TOTALS BY GRID METHOD	6.75	293366	3110	10.3	X			4.02		
TOTAL BY SINGLE AREA										

Figure 2

Irregularly shaped cells may be measured for area quickly and accurately by means of a polar planimeter. This device is analog instrument which traces the perimeter of an area to be measured and gives the size in actual square inches. This measurement is then multiplied by the square of the scale of the map being used. For example, 1" = 200', the square of 200 ft. means 1" equals 40,000 sq. ft. The total square footage of each cell can then be converted to acreage by dividing by 43,560 sq. ft. More detailed instruction in the use of the planimeter may be obtained from the City Planning Department.

Areas of irregular shape can also be measured by dividing each part into triangles, for which the areas are determined by the formula A = base x height ÷ 2, if a planimeter is not available.

Having now determined the area of each cell, one must now proceed to measure the contour lengths of the property. Contour length and interval are both vital factors in calculating the average slope of the land. Each contour of a specified interval is measured separately within each standard cell or other numbered zone for which the area has been calculated. The map wheel (Figure 3) is set at "zero" and is then run along the entire length of a contour within the boundary of the cell, lifted and placed on the next contour (without resetting the wheel to zero) and so forth until the total length of contours of the specified interval within the individual cell is determined. The map wheel will display a figure in linear inches traveled. This figure shown on the dial should then be multiplied by the map scale. (Example: map wheel reads - 14½ inches, map scale is 1" = 50'. Contour length = 14.5 x 50 = 750'). The results should then be entered on the proper line of Column D (Figure 2).

FIGURE 3
USING THE MAP WHEEL

Step Four: Calculation of Average Slope

Knowing the total length of contours, the contour interval, and the area of each numbered cell, one may now calculate the average slope of the land. Either of the two formulas below may be used to calculate average slope:

$$S = \frac{0.0023\ I\ L}{A}$$

APPLICATION OF 1/5
"FOOTHILL MODIFIED 1/2 Ac"
FORMULA
APPLICATION OF
"FOOTHILL MODIFIED"
FORMULA
APPLICATION OF
"SEMI-RURAL 8ac"
FORMULA
APPLICATION OF
"COUNTY III" FORMULA

FIGURE 4

S = average slope of ground in percent

I = contour interval in feet

L = combined length in feet of all contours on parcel

A = area of parcel in acres

The value 0.0023 is 1 sq. ft. expressed as a percent of an acre:

$$\frac{1 \text{ sq. ft.}}{43{,}560} = 0.0023 \text{ ac.}$$

$$S = \frac{I \times L \times 100}{A}$$

S = average slope of ground in percent

I = contour intervaling feet

L = combined length in feet of all contours on parcel

A = area of parcel and square feet

The results should be entered on the appropriate line of Column E of the worksheet.

Step Five: Determination of Dwelling Unit Credit

With the average slope of the cell now determined, one can calculate the dwelling unit credit per cell by obtaining a factor from the appropriate slope-density table (Section 3 of this document) then multiplying that factor by the area of the cell in acres. Refer to Figure 4 to ascertain which formula applies to the proeprty under investigation. The formula factor is found by first reading the table column "s" (slope) until reaching the figure corresponding to the average slope of the cell being studied; next, one reads horizontally to the "d" column (density D.U./gr. ac.). This factor should be entered in Column F of the worksheet. The factor in Column F is now multiplied by the acreage in Column B and the result entered under the appropriate slope-density formula title (Column G, H, I or J).

Step Six: Summation of Results

When all cells in the parcel have been analyzed in the manner previously described, total for various components of the data may be derived and entered into the two bottom rows of the worksheet. Columns B, C (if used), and D should be summed

at the bottom of the sheet. A mathematical average may be calculated for Column E. Columns G through J should be summed at the bottom of the pate. The totals shown at the bottom of Columns G through J represent the total number of dwelling units permitted on that property, based on the average slope. These totals should be carried out to a minimum of two decimal places.

Special Note: "Rounding" of Dwelling Unit Credit Results

The concept of "rounding" decimal fractions of total dwelling unit credit to the next highest whole number has been approved by the City Council. However, specific policies on the actual methodology of rounding will be established by ordinance at a future date.

Note:

Special instructions for slope-density calculation methods employing an electronic computer are also available from the Planning Department.